

R&D CONTRIBUTIONS TO AVIATION PROGRESS (RADCAP)

EXECUTIVE SUMMARY

(NASA-CR-129574) RESEARCH AND DEVELOPMENT
CONTRIBUTIONS TO AVIATION PROGRESS
(RADCAP): EXECUTIVE SUMMARY (Air Force
Dept., Washington, D.C.) Aug. 1972
39 p

N73-13984

CSCL 05D 13/34

Unclass
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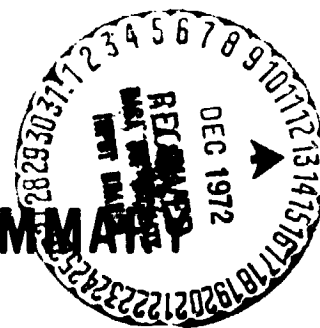


TABLE OF CONTENTS

	<i>Page</i>
Summary	1
The Radcap Study	2
Introduction	2
Major Technological Advances	5
American Aviation	
1925-1940	5
1941-1950	10
1951-1960	13
1961-1972	17
Technological Advance Review	22
Military R&D Relevancy	24
Commercial Airliner Development	27
Aeronautical R&D Funding	31
Findings and Observations	35

SUMMARY

More than eight out of ten of all the commercial jet airliners operating in the free world today were designed and built in the United States. That simple statistic is one measure of this country's preeminent position in aeronautics.

One out of every four of those American-built jet airliners traces its lineage directly to a single military bomber program. *That* simple statistic is a measure of the influence and importance of military aeronautical research and development.

All of the jet airliners—all of them—developed and built in the United States have depended to a large extent on the availability of technology, or hardware, or both, generated by military-sponsored programs in aeronautical research, technology, development or production.

Those are facts about today's commercial jet airliners. But they hold equally true, in a different sense, for all of civil aviation. For the study of the history of aeronautical progress in the United States shows that military sponsorship has provided most of the significant technological gains that have been made in American aviation.

This executive summary identifies 51 significant technological advances made in U. S. aviation since 1925. Military sponsorship has been responsible for 35 of them.

Government sponsorship, which included work funded by the military and by Government civilian agencies, was responsible for 45 of the 51 advances. The remaining six were results of work funded by private industry.

Forty-six of the 51 advances have been applied operationally. Of those, 31 were first used by the military, pioneering the way to later acceptance in civil aviation.

But there is more than this important direct transfer of technology and hardware from military programs to civil aviation. Additional extensive benefits have come from military sponsorship of new manufacturing technology, production methods, tooling, and factory and test facilities.

These vital contributions to the past growth of U. S. aviation helped establish the industry in its position as a world-recognized leader in aeronautical technology.

But recently, new and powerful factors have begun to influence the trends of these measurable contributions from military programs. Rising development costs, and foreign competition in technology, production and marketing, pose a serious threat to the continuing growth and progress of the U. S. aeronautical industry. The changing and evolving nature of the military threat is another major factor with powerful influence on the aeronautical industry.

The number of new aircraft program starts has been dramatically reduced over the past two decades, so that much valuable industrial momentum has been lost. Design teams have been broken apart, technical expertise scattered, and the art of design has—in some cases—stagnated.

All of these factors make the future uncertain, and perhaps gloomy, for this high-technology industry of aeronautics.



The Curtiss JN-4H, "JENNY," single-engine, 2-place, biplane. (Courtesy of The Air Force Museum)

THE RADCAP STUDY

This executive summary is based on the two volumes resulting from a detailed study of U. S. aeronautical progress since 1925. That study, *Research and Development Contributions to Aviation Progress* (RADCAP), is summarized in these pages. Conducted jointly by the Department of Defense, the National Aeronautics and Space Administration, and the Department of Transportation, the study had these broad objectives:

To identify the significant technological advances that have been made in U. S. aviation since 1925, and the background, sponsor, user, application, timing and trends of those advances.

To show the relevance of current and planned military aeronautical research and development to the research and development needs of civil aviation.

Stated simply, the study reviews the positive contributions of military aeronautical research and development programs to civil aviation, and assesses some possible future contributions of those military programs. It presents a major attempt to discover how the U. S. aviation industry progressed in past years, and how it may progress—or decline—in the future.

INTRODUCTION

The Curtiss JN-4H "Jenny" of 1925 and the Boeing 747B of 1972 have much in common, despite appearances: Both are airplanes, both carry passengers, both are supported in flight by their wings. The list is long.

But there is one major common factor, which is the reason for their shapes, their performances and their positions in history. Both these workhorse airplanes are representative of the broad application of contemporary aeronautical technology.

Technology is the common denominator of both designs. And the development of technology, from the knowledge that created the JN-4H to the expertise that developed the 747B, is one measure of aviation progress in the United States.

The Curtiss "Jenny" could carry one passenger and one pilot at a maximum speed of 93 miles per hour. In practice, this was reduced to a cruising speed near 75 miles per hour to save wear and tear and gasoline. The useful range was less than 200 miles. The maximum weight of the JN-4H was 2,145 pounds.

The Boeing 747B can carry from 374 to 490 passengers, depending on the internal arrangement of seats, at a cruise speed of 580 miles per hour, over a range of about 6,000 miles. Its maximum weight is 775,000 pounds.



The Boeing 747B, largest commercial transport in operation. (Courtesy of the Boeing Company)

Comparisons, although often odious according to the old saying, equally often can be interesting and enlightening. The interesting part of this comparison is that the 747B weighs as much as 360 "Jennies," and carries relatively few more passengers than 360 "Jennies" could. If the comparison stopped there, it would be odious.

The enlightening part of the comparison is to look at how many passenger-miles per hour could be flown by a single 747B and the armada of 360 "Jennies." The big Boeing transport can produce a maximum of 284,000 passenger-miles per hour. All those "Jennies" could produce less than a tenth of that number. That difference in productivity is one measure of the progress of aviation over the years since 1925.

These comparisons can be questioned, of course, because they are an oversimplification of the huge gap between the "Jenny" and the 747B. But they serve to illustrate the point: There has been an impressive growth of technology since 1925, and that growth has made it possible to build safe, economical transports that can carry hundreds of people over thousands of miles, day in and day out, nonstop, in fair weather or foul, and put them down gently and precisely on a distant runway.

That much generally is understood about today's aeronautical developments. That's *what* has happened since 1925. *How* it happened is a subject of this report.

The history of aviation progress is the history of a large number of significant breakthroughs in technology. There are some single developments, such as the jet engine, which loom larger in historical perspective than other tangible measures of progress. But over the years, it has been the steady building of technology by a discovery here and an invention there that has taken aviation to today's pinnacle.

How this progress was made has not been investigated in detail earlier. Public records in the press and in aviation histories generally deal with the spectacular achievements of individual pilots or aircraft in setting new records or establishing milestones along the route. But

those who work in the industry have long known that it was technology, as well as piloting skills, that made such records possible.

One example should emphasize this. When the Douglas DC-3 commercial transport first appeared in 1935 on the air routes of the world, it made obsolete, almost overnight, every other commercial transport then operating. The reason was that the DC-3 pioneered a number of new technologies. It had powerful, reliable air-cooled radial engines, driving controllable-pitch propellers. It used retractable landing gear to lower the drag in flight. It was built of new high-strength aluminum alloys. The engine was housed in a smooth cowl that improved the cooling and reduced the drag. It had trailing-edge flaps to slow the landing speeds.

In the hands of expert pilots, the DC-3 set new marks for operational performance and reliability. But without the new technology, those pilots would have been unable to accomplish anything except routine flying with mediocre performance.

The technology of the DC-3 was synergistic; the whole was greater than the sum of its parts. Each of those individual technological advances was a little breakthrough on the route of aeronautical progress.



The Douglas DC-3 earned the Collier Trophy for 1935 as the outstanding transport.

(Courtesy of the McDonnell Douglas Corp)

But there is a deeper significance to be found only by looking into the history of each of those—and other—technological advances. The deeper significance is that most of the technological advances that characterize the superb civil aircraft now in production and service in this country originated as results of military funding of aeronautical research and development.

The importance of that statement cannot be overemphasized. It's worth repeating, with different emphasis:

- Military funding of aeronautical research and development has been responsible for most of the technological advances in U. S. aviation.

The first task of the group which was assembled for the RADCAP study was to identify and evaluate the significant technological advances in U. S. aviation. If this had been the extent of the study, it would have produced a valuable

and interesting historical report. But past history has much to teach, and can serve as a useful point of departure for a look into the future.

Consequently, the study looks ahead to examine the current status of military aeronautical research and development, primarily from the viewpoint of its relevance to the pressing needs of civil aviation today. Those needs—such as the requirements for quieter, cleaner engines, eased air-traffic congestion, and new aircraft for the short haul—demand continuing advances in aviation. History shows that such improvements come primarily from military research and development programs in aeronautics.

Finally, because it takes money to support these programs, the study looks at long-term trends in funding of aeronautical research and development programs by Government and by private industry.

MAJOR TECHNOLOGICAL ADVANCES IN AVIATION

The first task of the Study Group was to determine which of the myriad developments over the years were the significant ones. Significance is a matter of opinion, ultimately, but there are criteria: Timeliness, magnitude, and value.

There were restrictions on selections, also, and the primary one was limiting them to aviation in the United States. Many significant advances in aviation occurred in foreign countries, sometimes long before they were recognized or applied here.

Final selections were made on the basis of available documentation, the recollections and judgments of the Study Group, and a very careful evaluation of all the advances that were suggested by these sources.

But such a selection does not recognize, let alone emphasize, the invaluable contributions of basic research, the painstaking development of engineering data, the complex interactions of people and organizations exchanging ideas and information, and the magnitude of the national commitment and involvement that made these advances possible. These factors, too, are vital for technical achievement.

Many advances would have been greatly delayed or even impossible without the availability of extensive and costly Government ground and flight research facilities. The role of such facilities has not been considered here to any extent, because it is far beyond the scope of this study. But the contributions of the U. S. Government, in providing these invaluable facilities, were vital to almost every advance.

The starting time for the study is 1925. That year marked a rebirth of purpose and a general reawakening of public and Governmental interest in U. S. aviation.

AMERICAN AVIATION: 1925-1940

In 1925, there were biplanes, frail creations of wood, wire and doped linen. Their speed and range were limited; their payloads were small.

Engines were heavy, and water cooled. Propellers were one piece, hand-carved of wood. Instruments were few and radios hardly to be found.



The Curtiss HAWK P-1 flew from New York to San Francisco in 1924. The trip required 21 hours and 48 minutes, including 5 stops.

(Courtesy of The Air Force Museum)

By 1940, the shape of airplanes and their construction had changed. They were monoplanes, of aluminum alloys with lightweight stressed skin and shell structures. Speeds and ranges increased spectacularly. Payloads were large enough to accommodate passengers, freight, weapons. Engines were both liquid- and air-cooled, tucked inside sleek sculptured metal cowlings. All-metal propellers could change their blade angles in flight for greater efficiency. Instrument panels were dotted with a host of new indicators that helped the pilot to fly without seeing either the ground or the horizon. And radios linked him to the ground or to other aircraft.

The barnstormers began the peacetime exploitation of aviation after World War I. Their surplus military trainers were the first contact many Americans had with an airplane, in exciting rides above the spire of their church and the tower of the city hall.

In 1927, Capt. Charles A. Lindbergh's solo flight across the Atlantic captured the imagination of the country and started a feverish enthusiasm for aviation that was not to cool off for several decades.

The Atlantic was crossed again and again; the Pacific was traversed in a series of flights. Speed records were broken, altitude marks fell, and long-distance flights became commonplace. Endurance flights were as popular a spectacle as flagpole sitting.

America's first airlines began scheduled services, and small airplanes designed specifically for private owners made their first appearances.

The industry grew from small shops in hangars at remote airports to major factory complexes employing thousands and gearing for the war that was sure to come.

Wars between Japan and China, Italy and Abyssinia, and the civil war in Spain catapulted military aviation to the headlines. The second of the devastating world wars began near the end of this period. The brutally efficient use of airpower in support of the German armored thrust into Poland impressed and frightened the world.

SIGNIFICANT TECHNOLOGICAL ADVANCES: 1925-1940

From 1925 to 1940 the airplane had under-

gone a metamorphosis. Its shape, construction, power plant, instruments and capabilities had improved many times over. It had become a vehicle for passenger-carrying, for freight-hauling, for sport, for pleasure, and for lightning war.

The differences between the slow biplanes of 1925 and the speedy monoplanes of 1940 were measured by many advances in technology, in new developments that increased engine power and efficiency, reduced drag, lightened structures, and improved the safety and economy of flight.

The significant technological advances of this time period are summarized in Table 1 and discussed in more detail in the following pages of this summary report. Additional details may be found in Volumes I and II of the RADCAP Study.

In this table, and the others within this chapter, the date listed for each advance is tied to a significant event in the United States, such as full development of an idea, discovery of something new, or the development of hardware. The sponsor is the primary source of funding for the advance, rather than the originator of the need, or the producer of the work. The date under the user listing refers to the application or use in operational or service aircraft. In many cases, it is the first flight date of an aircraft using the specific advance.

The Curtiss P-40 in 1940 bore little resemblance to the original HAWK.
(Courtesy of The Air Force Museum)



TABLE 1. Significant Technological Advances: 1925-1940

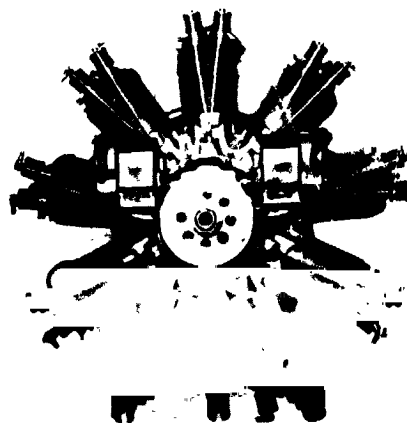
ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
RADIAL AIR-COOLED ENGINE	1920	GOVT MIL	1922	1925
RETRACTABLE LANDING GEAR	1921	GOVT MIL	1931	1930
STANDARD ATMOSPHERE DATA	1925	GOVT CIV	1925	1925
SUPERCHARGING	1927	GOVT MIL	1930	1930
HIGH-LIFT DEVICES	1927	PVT SECT	1932	1933
NACA COWLING	1928	GOVT CIV	1932	1929
DE-ICING	1928	GOVT CIV	1935	1935
TWO-WAY RADIO COMMUNICATION	1928	GOVT MIL	1928	1929
STRESSED-SKIN METAL AIRPLANE	1930	PVT SECT	1930	1930
HIGH-STRENGTH ALUMINUM ALLOY	1931	PVT SECT	1935	1935
CONTROLLABLE-PITCH PROPELLERS	1932	GOVT MIL	1933	1933
AUTOMATIC PILOT	1933	PVT SECT	1936	1935
HIGH OCTANE FUELS	1936	GOVT MIL	1936	1946
CABIN PRESSURIZATION	1937	GOVT MIL	1937	1938

Note: *NACA—National Advisory Committee for Aeronautics.

Four of these significant technological advances produced major gains in power-plant performance, which resulted in better aircraft range, speed, payload and economy. These four were:

- *Radial air-cooled engine*, which grew from 200 horsepower near the beginning of this period to nearly 10 times that figure by the end of 1940. Pioneered by development contracts from the Army and Navy in 1920, this new engine type began military flight test in 1922 and powered this country's first commercial transports in 1925.
- *High-octane fuels*, which led the way to higher engine performance from more efficient combustion. In 1936, both the Army Air Corps and the Navy standardized on 100-octane fuel; commercial use of the higher cost 100-octane fuel began after World War II.

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The Lawrance Model J-1 was the forerunner of the famous Wright "Whirlwind" series.
(Courtesy of The Air Force Museum)

- *Supercharging*, which made it possible to produce and sustain high performance at high altitudes. Although the military had funded supercharger development as early as 1918, it was not until 1927 that the first U. S. production engine was equipped with a gear-driven supercharger. From 1930 on, all military and transport engines had gear-driven superchargers. The first military application of turbosupercharging to a production aircraft was made in 1923; first commercial use of turbosupercharging occurred in 1949.
- *Controllable-pitch propellers*, which improved propulsive efficiency over the speed range from takeoff to high-speed flight. Developed in 1932, controllable-pitch propellers were applied on Navy fighters and commercial transports the following year.

Four major advances changed the looks and construction methods of aircraft for all time, and produced further gains in safety, performance, and economy:

- *Retractable landing gear*, which markedly reduced airplane drag, improving climb and level-flight performance in almost every category. Tested successfully by the Army Air Service in 1921, the use of retractable gear was pioneered by a commercial transport in 1930. The following year a Navy fighter became the first military aircraft to use the gear.



The Lockheed "Air Express" was one of the first transport aircraft to utilize the N.A.C.A. cowling.
(Courtesy of The Air Force Museum)

- *NACA cowling*, a 1928 development which reduced the drag of the radial air-cooled engine and improved its cooling, producing the equivalent of a major increase in effective horsepower. It was first used on a civil aircraft in 1929 and on an Army bomber in 1932.
- *Stressed-skin metal airplane*, a new design and construction technique that made it possible to build the aerodynamically efficient cantilevered-wing monoplane. It was first applied almost simultaneously to a civil transport and an Army pursuit plane in 1930.



The Boeing "Monomail" started a new trend in transport aircraft design.
(Courtesy of The Air Force Museum)

- *High-strength aluminum alloy*, which coupled new and high levels of strength with the lightness of the base metal to improve structural efficiency. Developed by industry in 1931, high-strength aluminum alloys had been adopted for both civil and military aircraft by 1935.

The handling and control characteristics of aircraft are directly related to their safety. During this time period, two major technological advances in aircraft handling and control led to easier and safer flying:

- *High-lift devices*, typified by landing flaps which improve landing performance by reducing the approach speed and increasing the approach angle. Invented and applied privately as early as 1927, flaps were installed on a civil transport in 1933. The earliest recorded military use was in 1936.
- *Automatic pilot*, which relieves the pilot of a major portion of his work load during long flights, and reduces the need for manual navigation methods. Developed to successful use by 1933, the autopilot was installed in production civil transports first in 1935, and in an Army bomber in 1932.

The early hazards of flying were due often to unknown and unsolved problems resulting from gaps in the knowledge of weather, aerodynamics, navigation, or communications. Four technological advances during this time period reduced the number of unknowns that could bedevil pilots:

- *Standard atmosphere data*, the first compilation of available knowledge about the atmosphere for use in aircraft and equipment design. Described by NACA in a 1925 data book, this first step to define a standardized atmosphere led to the development of upper-air observations that paved the way to accurate aviation weather forecasting.

- *De-icing*, which licked the ancient enemy of airmen by removing ice as it formed on wings and other aircraft surfaces. A 1928 interagency conference initiated this development, and the results—de-icing systems—had been adopted by 1935 on commercial transports and military bombers.
- *Cabin pressurization*, which surrounded the pilot—and later his passengers—with a generated environment capable of supporting life at extreme altitudes. The Army Air Corps proved its feasibility first in 1937; the first civil application was made the following year.
- *Two-way radio communication*, which linked the pilot to ground stations along his route and to other aircraft, giving him information that would speed him safely on his way. By 1928, the military had installed two-way radios in its aircraft; commercial aviation followed in 1929.

Seven of these 14 technical advances came from Government military research and development programs, and three more from Government civil agency R&D. The remaining four were developed by the private sector of industry. Pioneering these advancements through early use was shared equally by military and civil aviation.



The Curtiss P-40 employed simple wing flaps to increase the lift and drag of the wing.
(Courtesy of The Air Force Museum)



The Boeing B-17E "Flying Fortress."
(Courtesy of The Air Force Museum)

AMERICAN AVIATION: 1941-1950

This time period saw a second revolution in aircraft technology, born of the demands of World War II. In the historically brief period of the war, the shape of aircraft changed once again to new and sometimes startling designs that set the styles for most of today's airplanes.

Those years saw the use of wing sweepback as a means of reducing drag; the birth and maturing growth of the jet engine; the development of research aircraft to investigate, in flight, new reaches of speed and altitude.

The synergistic combination of the sweptback wing and jet propulsion was basically responsible for a new generation of aircraft designs born during the last years of the war. Sweepback had been suggested earlier by scientists in several countries, but the Germans were the first to exploit it in the development of their last-ditch fighters. Jet propulsion grew from simultaneous work in Great Britain and Germany; both countries had operational jet fighters by 1945.

The last years of that war saw the planning of the "X" series of research aircraft, a new approach to flight research undertaken by the NACA in cooperation with the Army and Navy.



The Boeing B-17B proved to be the most important forerunner to the development of U.S. commercial jet transports. (Courtesy of The Air Force Museum)

From those aircraft came the first supersonic research airplane, the Bell XS-1, that pioneered the realm of flight beyond what was then called the sonic barrier.

Postwar aviation development was characterized by rapid and revolutionary growth in military and commercial aviation. Jet fighters set new speed and altitude records; bombers and patrol planes established new distance marks.

In 1944, the U. S. aviation industry was the largest single industry in the world. Its production of 96,000 aircraft represented a value of \$17 billion, then more than 10 percent of the gross national product. In 1945, the industry was decimated by loss of contracts for more than \$26 billion. But by 1950, the postwar recovery had begun; production had climbed back to 6,000 aircraft and sales were more than \$3 billion.

The four-engined transport planes, tempered and proven in military service during the war, grew into a series of new commercial airliners that expanded domestic and worldwide passenger services, and created global markets for U. S. commercial aircraft. By the end of this time period, the world's airlines were turning increasingly toward the United States for designs of efficient and economical transports.

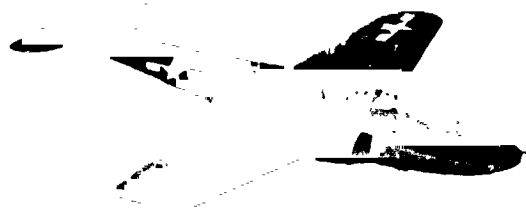
SIGNIFICANT TECHNOLOGICAL ADVANCES: 1941-1950

The demands of war were responsible for most of the advances in technology during this time period. Military requirements for more speed, altitude, range, load-carrying capability, and the ability to fly in bad weather were the spurs.

The advances made during this time period are summarized in Table 2 and described in more detail in the pages that follow.

Four of these advances contributed to major, and even spectacular, improvements in aircraft performance:

- *Turbojet engine*, which eliminated the performance limitations of propeller-driven planes, and opened the way to flight at very high altitudes and speeds. The first U. S. work was sponsored by the military in 1941, and the first U. S. jet-propelled air-



The Bell XP-59 was America's first jet-propelled fighter.
(Courtesy of The Air Force Museum)

craft, an Army Air Force experimental pursuit, flew in 1942. Not until 1954 did a U. S. civil design, a commercial transport, use jet engines.

TABLE 2. Significant Technological Advances: 1941-1950

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
HELICOPTER	1941	PVT SECT	1942	1946
ADHESIVE BONDING	1941	GOVT MIL	1942	1958
TURBOJET	1941	GOVT MIL	1942	1954
INSTRUMENT LANDING SYSTEM	1941	GOV JOINT	1943	1947
SWEPTBACK WING	1945	GOVT CIV	1947	1954
DELTA WING	1945	GOVT CIV	1948	--
FATIGUE TESTING	1946	GOVT MIL	1948	1947
THRUST REVERSER	1946	GOVT MIL	1963	1954
ON-BOARD POWER GENERATION	1946	GOVT MIL	1946	1955
TITANIUM	1947	GOVT MIL	1952	1954
SUPERSONIC FLIGHT	1947	GOVT MIL	1953	--
GROUND-BASED WEATHER RADAR	1948	GOVT MIL	1948	NA*
DOPPLER NAVIGATION RADAR	1949	GOVT MIL	1954	1955

*NA—Not applicable; private industry does not currently operate weather radars, nor does it need to do so.

- *Sweptback wing*, which delayed the drag rise near the speed of sound and—in application with the turbojet engine—raised performance to the edge of the sonic speed range. In 1945, NACA published the first U. S. report on the theory of sweptback wings. Two years later, two U. S. Air Force prototypes with swept wings made their first flights. The first use on civil aircraft was in 1954, on a commercial jet transport.



The North American F-86 was one of the first U.S. fighters with swept wings.
(Courtesy of The Air Force Museum)

- *Delta wing*, which pioneered a shape uniquely planned for supersonic flight. Developed in Germany during the war, and tested by NACA in 1945, the delta wing was first used on a military aircraft in 1948.
- *Supersonic flight*, which proved that the sonic barrier was an exaggeration and that sustained flight above the speed of sound was possible, advantageous and controllable. The XS-1 research aircraft led the way in 1947, and by 1953 the U. S. had a production fighter capable of sustained supersonic flight.

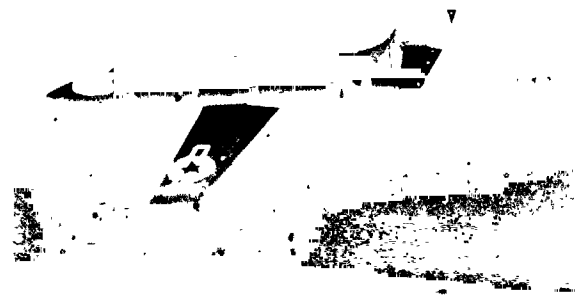
The combination of the turbojet engine and wing sweepback gained a new range of speed performance, where loads were higher and different in character from those encountered in the earlier years of flight. Three significant

advances helped increase the knowledge of aircraft structures and improve their fabrication:

- *Fatigue testing*, a 1916 development which isolated and analyzed the problem, and led to new theoretical and empirical methods of structural design. In 1947, a civil transport became the first complete aircraft to be tested for fatigue life, and the Air Force first used full-scale fatigue testing in 1948 to improve the service life of a fighter.
- *Adhesive bonding*, an industrial development of 1941 which replaced rivets, screws and bolts in some aircraft components and led to lighter and simpler structures. The first military use was in 1942; the first civil applications were not made until 1958.
- *Titanium alloys*, developed under Navy sponsorship that started in 1947, which contributed to the successful development and production of high-performance military and commercial jet engines.

The postwar growth of civil aviation was one of the factors that led to safer and more reliable flight operations during this period. More airplanes with higher performance, operated by both the military and civil owners, spurred the developments which resulted in five major technological advances in flight operations and safety:

- *Instrument landing system*, which created a "highway in the sky" to lead pilots to safe landings in bad weather or at night.



The Bell XS-1. (Courtesy of The Air Force Museum)

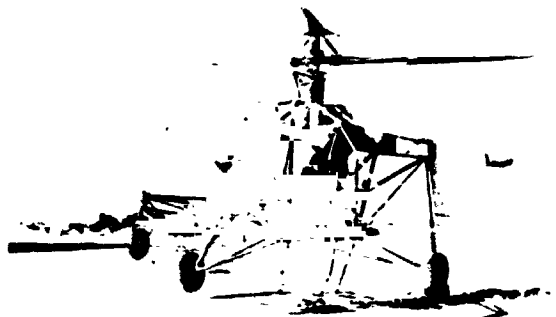
Stemming from an Air Corps specification issued in 1941, the instrument landing system was first installed in 1943 in military aircraft, and in 1947 in commercial transports.

- *Ground-based weather radar*, which can detect and track hazardous storms, and assist aircraft in avoiding them or safely penetrating them. The Army developed the first such unit in 1948, and use by the military followed immediately.
- *Doppler navigation radar*, which is a self-contained navigating system, independent of ground stations. The first units were delivered to the Air Force in 1949, and installed as standard equipment in operational fighters in 1954. The first commercial Doppler unit was built in 1955.
- *On-board power generation*, using constant-speed drives and three-phase, 400-cycle, 120/208-volt systems in small, lightweight packages. Developed and applied by the military in 1946, these systems became standard on commercial transports as well beginning in 1955.
- *Thrust reversers*, which capture a major fraction of the jet engine's power and, by reversing the exhaust flow, use it to slow down aircraft either independently or working with standard wheel brakes. Although Navy-sponsored flight tests took place in 1946, it fell to commercial transports to pioneer thrust reversers first, in 1954. Military applications began in 1963.

This time period saw the successful introduction of a unique aircraft, a singularly significant advance:

- *The helicopter*, which separated aircraft from their traditional dependence on runways by its unusual ability to take off and land vertically, to hover, and to move laterally and backward as well as forward. Developed and demonstrated by private industry first in 1941, the helicopter was first used by the Army in 1942 and by civil operators in 1946.

Nine of these advances derived from Government-sponsored military research and develop-



The Sikorsky VS-300 makes its first flight.
(Courtesy of The Air Force Museum)

ment programs, and two came from Government civil agencies' work. One was a joint project of Government military and civil agencies, and one originated in the private sector. All but two were first used by the military.

AMERICAN AVIATION: 1951-1960

The previous decade had established the jet age. The years from 1951 to 1960 saw its lusty growth to embrace almost all new military aircraft, as well as a growing number of commercial transports.



The Douglas DC-6B appeared in 1950.
(Courtesy of The McDonnell Douglas Corp)

The earlier achievement of supersonic flight became a routine accomplishment by military aircraft developed during this decade. The helicopter, flown heroically during the Korean conflict, demonstrated dramatically its unique potential for rescue operations and short-haul transportation in and out of limited and confined spaces. Its performance—and its drawbacks—sparked interest in a new field: vertical takeoff and landing (VTOL) aircraft. The first U. S. prototypes of this unusual class of aircraft, designed to lift off and land vertically but to cruise horizontally for longer ranges and higher speeds than those obtainable with helicopters, were developed during this decade.

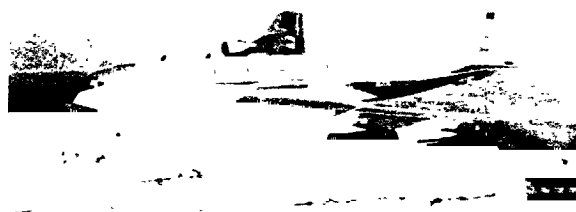
Military aviation continued to grow rapidly. The first all-jet aerial combat was joined over Korea in 1950. During that conflict, the swept-wing fighter replaced its older straight-winged sisters in service with the Air Force and Navy. The speeds of operational military aircraft doubled during this decade, and higher altitudes became normal cruising grounds.

The "X" series of research aircraft pioneered a number of unusual shapes in the air, ranging from the stiletto-like lines of the Douglas X-3 through the variable-sweep wings of the Bell X-5. The Northrop X-4 investigated the potential of tailless aircraft in the high-speed regime. The Bell X-2 rocket-powered craft reached an altitude above 126,000 feet and a speed faster than three times the speed of sound. Near the end of the decade, the North American X-15 hypersonic research aircraft began its flight program that would see it touch altitudes and speeds not exceeded until manned spacecraft were first flown.

Both the B-47 and the B-52 swept-wing jet bombers joined the Air Force inventory during this decade. The B-47 had made its first flight in 1947, the B-52 in 1952.

One of the most lasting and significant events of the decade occurred about midway through those years. The canary- and chocolate-colored Boeing 367-80, progenitor of a long-lived series of commercial jet transports, took to the air on its first flight July 15, 1954. Drawing heavily on Boeing's experience with the

B-47 and B-52 bomber programs, the Model 367-80 was developed into the Boeing 707 series, which first entered commercial service in 1958.



The Boeing 707-320 at the end of the decade.
(Courtesy of The Boeing Company)

At the beginning of this period, passenger miles flown exceeded passenger miles traveled in Pullman cars for the first time in history, and the trend never reversed from then on. At the end of this decade, more than 80 percent of all the world's commercial air transport fleet had been manufactured in the United States.

Near the end of this period, the advent of the ballistic missile and the successful launching of the earth's first artificial satellite by the Russians placed new emphasis on technology.

SIGNIFICANT TECHNOLOGICAL ADVANCES: 1951-1960

With the maturing of the jet age, new demands for improved performance of aircraft hastened the advance of technology. The arrival of missiles—and later, spacecraft—on the aviation scene led to new approaches to manufacturing and design because of volume and weight restrictions. And the explosive growth of airborne electronics was another characteristic of the technology of this period.

The significant technological advances of the years between 1951 and 1960 are summarized in Table 3 and discussed in more detail in the pages that follow.

TABLE 3. Significant Technological Advances: 1951-1960

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
HEAVY PRESS PROGRAM	1951	GOVT MIL	1954	1956
NUMERICALLY CONTROLLED MACHINES	1951	GOVT MIL	1956	1956
AREA RULE	1952	GOVT CIV	1954	1962
BLOWN FLAP	1953	GOVT MIL	1954	--
INERTIAL NAVIGATION	1953	GOVT MIL	1963	1967
SONIC FATIGUE TESTING	1955	GOVT MIL	1956	1957
TURBOFAN ENGINE	1956	GOVT MIL	1961	1960
AIRBORNE DIGITAL COMPUTER	1957	GOVT MIL	1957	1967
COMMUNICATIONS SATELLITE	1958	GOVT MIL	1966	1962
COMPUTERIZED FLIGHT PLANS	1959	GOVT MIL	1959	1961
DIGITAL FLIGHT SIMULATORS	1960	GOVT MIL	1960	1963
WEATHER SATELLITES	1960	GOVT CIV	1960	1960

Four major advances that improved aircraft performance paced the early years of this time period:

- *Area rule*, an aerodynamic development from the wind tunnels of NACA in 1952, reduced greatly the flow breakaway and turbulence that caused high airplane drag at high subsonic speeds. First applications to military aircraft were made on Navy and Air Force fighters which first flew in 1954; the first civil use occurred in 1962 on a commercial transport.

- *Blown flap*, which used some of the energy available from the jet engine to increase flap effectiveness for landing and takeoff. First fitted experimentally to a Navy fighter in 1954, blown flaps—which gain their performance from extra air blasted over the leading edge of the flaps—have been fitted to production military aircraft.



The Convair F-102A was among the first advanced aircraft to make use of the Area Rule developed by N.A.C.A. (Courtesy of The Air Force Museum)

- *Turbofan engine*, a more versatile class of jet power plant with improved performance and reduced fuel consumption and noise. First constructed in 1956 under military sponsorship, the turbofan was first applied to a commercial transport in 1960, and to a military bomber in 1961.
- *Sonic fatigue testing*, which evaluated the problems of structures buffeted by the noise energy in a jet exhaust or high-speed airflow. First established as a program in 1955 by the military, sonic fatigue testing established the safe life of a bomber the following year and aided the design of commercial transports in programs that began in 1957.

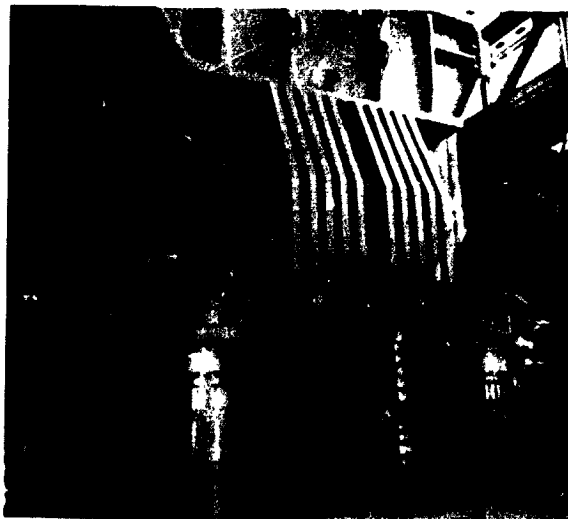
Improvements in aircraft performance brought new requirements for stronger, still lighter structures, with large, aerodynamically smooth areas uncluttered by seams and joints which could increase drag. Two major advances in manufacturing technology helped meet those needs:

- *Heavy press program*, which added huge forging and extrusion presses to the country's metal-working capabilities. Established by the military in 1951, the program produced large components of steel and titanium as the first pieces of a new generation of aircraft. In 1954, the first parts for a military aircraft were fabricated on the giant presses; two years later, the first components for a civil transport were built.
- *Numerically controlled machines*, which eliminated much of the manual drafting, machine-operating and checking by using programmed punch-cards or tape. Parts interchangeability could be assured, because dimensionally identical units could be built in two or more factories. Numerical control is used in nearly three-quarters of all the metal removal done in aircraft fabrication today. The first military contract for this development was awarded in 1951, and the first application to aircraft production was in 1956.

Airborne electronics took over some of the tasks of pilots, gunners, observers and other

crewmembers in military aircraft, and they aided flight crews flying the new jet transports of this period. Three significant advances were made in airborne electronics during these years:

- *Inertial navigation*, which measures the position in space of an aircraft without recourse to externally generated information such as radio or radar beams or nets. Developed in 1953 under military sponsorship, inertial navigation systems were installed first by the military in 1963. Their first civil use was in 1967.
- *Airborne digital computer*, which handles the complex equations of flight with ease, speed and accuracy, doing tasks that could not be performed by human operators within the time frame of the flight. The first military use was in a fighter weapons-control system in 1957. Commercial application was in 1967.
- *Communications satellite*, which provides a global coverage not achievable with any other form of communications network, however complex. Originally demonstrated in 1958, communications satellites were first utilized in commercial television in 1962. The initial launch of the Defense communications satellite system took place in 1966.



Large forging presses, 35-50,000 ton, were first used to manufacture parts for the B-52.
(Courtesy of The Air Force Materials Laboratory)

Reliability and safety of flight operations are always major considerations of both military and civil operators of aircraft. They look for continuing advances in technology to keep pace with performance advances in the aircraft they operate. During this time period, three significant advances occurred in flight operations:

- *Computerized flight plans*, which print out in detail the course data, weather, fuel consumption, and other pertinent factors for flight crews. These were pioneered in 1959 by the military and adopted in 1961 by commercial airlines.
- *Digital flight simulators*, which first made it possible to simulate flight operations in real time and with six degrees of freedom in the motion equations. This development was first demonstrated in 1960, in a military application. The first unit for commercial airline application was delivered in 1963.
- *Weather satellites*, which maintain a global weather watch and can alert forecasters to the formation of storms or other unfavorable flying conditions. The first weather satellite was launched in 1960 under Government sponsorship, and its data found immediate use by both the military and civil aviation sectors.

All 12 technological advances of this period resulted from Government-sponsored research and development programs, 10 of them conducted for the military. Eight were pioneered through military first use, two were used for the first time simultaneously by military and civil operators, and two were initially applied by the civil sector.

AMERICAN AVIATION: 1961-1972

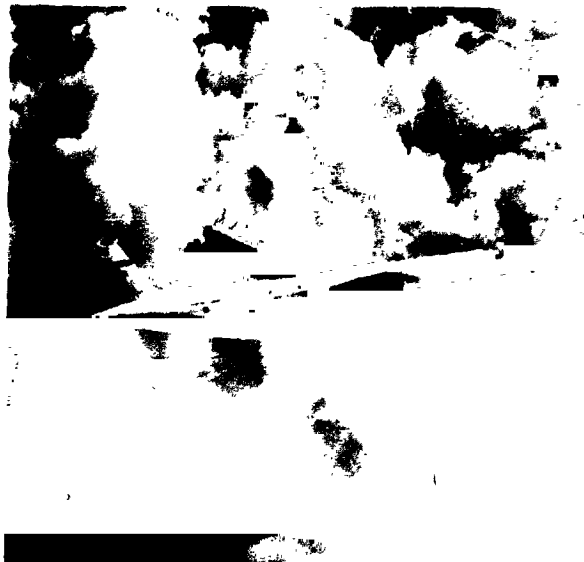
Just 3 years before this time period began, there were no jet transports in service. By 1972, there were close to 5,000 jet transports of all sizes flying the trade routes of the upper air. Jet travel started on the new North Atlantic "blue ribbon" runs, thousands of feet above the wakes of the diminishing number of

passenger-carrying ships. In 1958, the airlines carried more travelers across the Atlantic than ships did, for the first time in history. From then on, the passenger liner was doomed, along with a life style and a mystique that had lasted for more than a century.



The Boeing 727 was one of the new transports entering service during the early 1960's.
(Courtesy of The Boeing Company)

A similar phenomenon was being repeated on overland routes. At first on the long-haul runs between coasts and then on the shorter legs between major cities, jet transports took on the loads that had been carried for years by the piston-engined straight-winged derivatives of World War II military transports. Passenger statistics grew every year as more and more people discovered jet travel. And, as the demand for jet transportation increased, so did the number of new designs. The jet grew more versatile, and its performance, reliability and safety were heightened by technological advances: The turbo fan engine, high-lift devices, new and lighter high-strength structures. At one end of the scale, it grew to a very large size, capable of carrying almost 500 passengers. At the other, it was a small transport built specifically for business and executive travel and capable of carrying as few as four passengers efficiently. In between was a choice that would suit almost any airline for almost any task, from crossing the wide Pacific to flying intrastate commuter runs.



The Lockheed C-5A.
(Courtesy of The Air Force Museum)

The traveling public loved it. Jet travel was fast and smooth. But externally the jets were noisy, and public pleasure was countered by the first signs of widespread community displeasure with aviation. Aircraft noise and visible pollution had their impact on community planning and on the slowdown in airport expansion and construction that marked the last few years of this time period. Public fears concerning the supersonic transport, justified or not, were influential in congressional voting against further funding for that program.

One major influence on aviation during this period was the struggle in Southeast Asia, with its extensive use of the widest variety of aircraft in traditional and new tasks. A most significant aspect of that struggle has been the enormous amount of helicopter operational experience gained by the Army and the Marine Corps and the resulting advances in helicopter technology. New, widespread applications of this aircraft will surely follow, just as earlier pioneering of the helicopter in Korea helped to establish it as a unique aircraft type in civil use after that conflict.

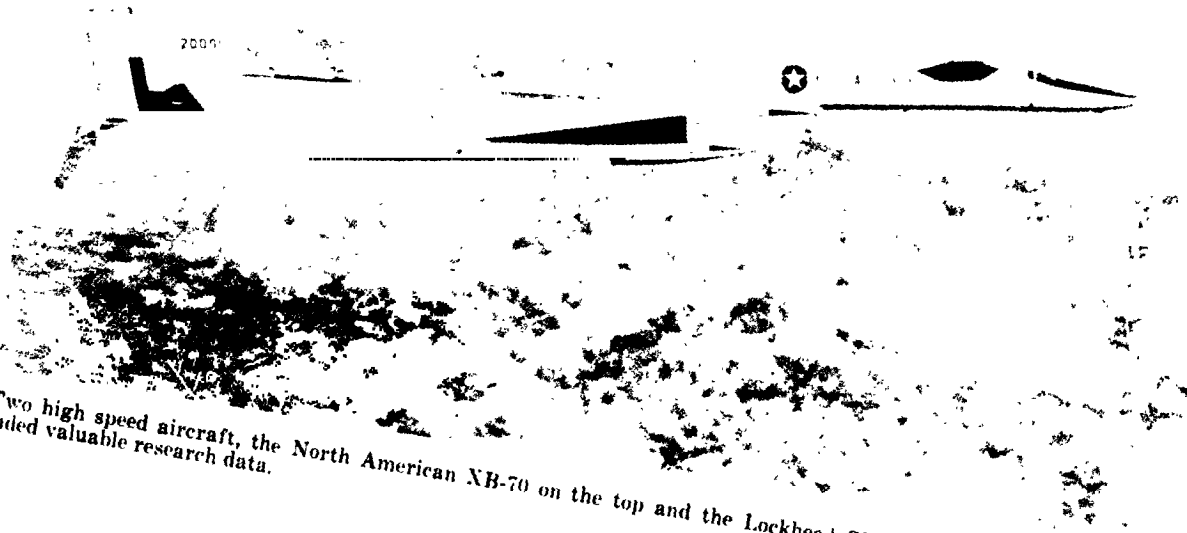


The Boeing Vertol CH-47 performs many rescue and evacuation operations in Southeast Asia.
(Courtesy of The Air Force Museum)

Competition from foreign industry began to be felt in export sales of U. S. aircraft. New foreign commercial transport designs threatened to take a larger portion of the worldwide aviation market away from U. S. industry. And American airlines were faced with the possibility of buying a foreign supersonic transport in order to compete on their international routes.

In 1960, the Apollo program was established. It was to become significant to aviation because of the range of the new technology generated by the needs of lunar exploration.

During this time period, several significant aircraft flew for the first time: The giant North American XB-70 supersonic bomber prototype, which provided much useful flight research data for high-speed aircraft design; the Lockheed A-11, in later form to be designated the SR-71 and YF-12A, that slashed through the skies at three or more times the speed of sound; and the experimental Vought-Hiller-Ryan XC-142A, a tilt-wing V/STOL aircraft.



Two high speed aircraft, the North American XB-70 on the top and the Lockheed SR-71 on the bottom, have provided valuable research data.
(Courtesy of The Air Force Museum)

SIGNIFICANT TECHNOLOGICAL ADVANCES: 1961-1972

These recent years have seen no let-up in the pace of aeronautical development. The advances in technology continue, spurred by the demands for continuing improvements in aircraft performance, safety and economics.

These advances are summarized in Table 4 and discussed in more detail in the following pages.

Four significant advances occurred in this period which made improvements in the design, construction and propulsion of aircraft:

- *Single-pivot variable-sweep wing*, which makes this valuable aerodynamic scheme practical for efficient flight at both high and low speeds. This layout was conceived by the National Aeronautics and Space Administration (NASA) and applied first to an Air Force fighter-bomber in 1965.



The General Dynamics F-111 utilizes the single-pivot variable-sweep wing.

(Courtesy of The Air Force Museum)

- *Supercritical wing*, which improves high-speed flight performance by further delaying the drag rise that occurs near sonic speed. It was developed in wind tunnels of the NASA in the mid-1960s, and flight research began in 1970.

TABLE 4. Significant Technological Advances: 1961-1972

ADVANCE	DATE	SPONSOR	USER	
			MIL	PVT SECT
ADVANCED COMPOSITES	1961	GOVT MIL	1969	--
MICROELECTRONICS	1961	GOVT MIL	1963	1969
FOG DISPERSAL	1963	PVT SECT	1967	1963
NAVIGATION SATELLITE	1964	GOVT MIL	1964	--
V/STOL RESEARCH AIRCRAFT	1964	GOVT MIL	--	--
AIRBORNE PHASED-ARRAY RADAR	1965	GOVT MIL	--	--
SINGLE-PIVOT VARIABLE-SWEEP WING	1965	GOVT MIL	1965	--
LOAD ALLEVIATION AND MODE CONTROL	1965	GOVT MIL	1971	--
HIGH BYPASS RATIO TURBOFAN	1967	GOVT MIL	1968	1970
SUPERCritical WING	1970	GOV JOINT	--	--
FLY-BY-WIRE	1970	GOVT MIL	--	--
ADVANCED BLOWN FLAPS	1970	GOVT CIV	--	--

- *Advanced composites*, new materials which produce structural components of extremely high strength- and stiffness-to-weight ratios. The development was initiated by military sponsorship in 1961; the first batch of components using these materials was built in 1969 for service testing on a military fighter.
- *High-bypass-ratio turbofan*, a new engine class which shows a major increase in thrust without a corresponding weight increase and features reduced fuel consumption, noise and pollutants. Developed in 1967 under military sponsorship, this class of engine first was installed in a military transport in 1968 and on civil transports in 1970.

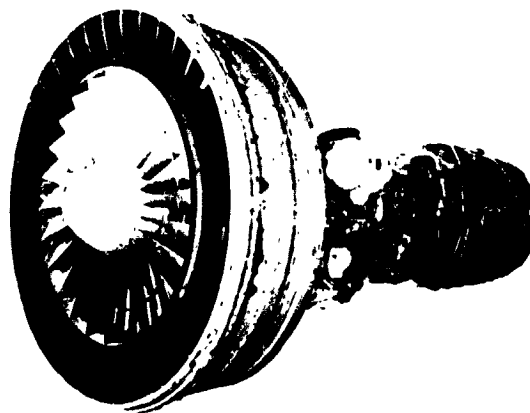
As performance increases, so does the concern about the ability of a pilot to control his aircraft in all the areas of its performance envelope. Two significant advances were made in flight controls during this period:

- *Load alleviation and mode control*, which enables an aircraft to sense air disturbances and adjust its controls to minimize effects on the flight path and the structure. The Air Force initiated this program in 1965, and in 1971 completed the modification of operational bombers to use this system.
- *Fly-by-wire*, which replaces the mechanical systems of current aircraft with electrical circuits for primary flight control, with major weight savings. The first significant flight testing of such a system was done by the Air Force in 1970.

Two of the most significant advances of this time period occurred in electronics:

- *Microelectronics*, in which complete electronic circuits are fabricated on a tiny "chip" smaller than a fingernail. Production processes for these circuits were demonstrated in 1961 under military sponsorship, applied by the military in 1963, and later applied to commercial systems in a civil transport which flew in 1969.
- *Airborne phased-array radar*, which uses fixed elements to scan electronically, and

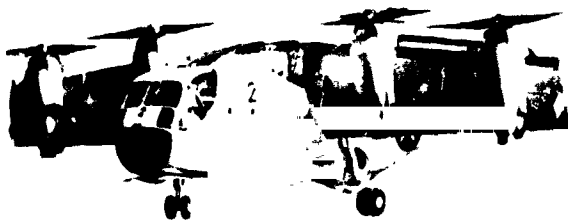
has the capability of simultaneously doing several tasks, such as target tracking, navigation and weapons delivery. Both the Navy and the Air Force initiated development programs in 1965, and prototype systems have been tested.



The General Electric TF-39 powers the C-5A.
(Courtesy of The Air Force Aero Propulsion Laboratory)

The increased interest in vertical and short takeoff and landing (V/STOL) aircraft during this time period sparked these advances:

- *V/STOL research aircraft*, which showed in a variety of design forms the unique capabilities and some of the problems of these unusual aircraft. Prototype aircraft developed under a tri-service military program and incorporating three different propulsion concepts made initial flights in the mid-1960s. Recently a production V/STOL attack aircraft, the Hawker-Siddeley "Harrier," was deployed operationally by the Marine Corps.
- *Advanced blown flaps*, which show promise of early application to both civil and military transports that could be safe, quiet and efficient. Programs to develop such flaps were begun in 1970 under Government sponsorship.



The Ling-Temco-Vought XC-112A tri-service assault transport executing a hover maneuver with the wing tilted at a 90-degree angle.
(Courtesy of The Air Force Museum)

In flight operations, the problems of weather were reduced again and navigation was made easier by two significant advances:

- *Fog dispersal*, which attempts to dissipate the dangerous cold fogs that can close airports to traffic with a resultant economic impact on the airlines. Localized dry-ice seeding of cold fogs at airports was first done by a commercial airline in 1963, and the technique then developed was adopted by the Air Force in 1967.
- *Navigation satellite*, which established the first of a series of check points in the heavens as an aid to extremely accurate navigation. Early military experiments in 1964 led to the currently operational systems and to projected future systems with a wide variety of applications.

With one exception, all of the above advances came from Government-sponsored research and development programs. One of the Government programs was jointly funded by the military and a civilian agency, one was funded only by a civilian agency, and the other nine were the results of military programs. Most of the advances have not yet been applied in civil aviation; four of them have not been applied in either civil or military aviation.

TECHNOLOGICAL ADVANCE REVIEW

These 51 significant technological advances occurred from 1925 through 1972. The largest number of them resulted from initial, and often continuing, military sponsorship and application. Civil agencies in Government accounted for a substantial but much lower percentage of the total. Advances funded by the private sector were substantial only in the 1925 to 1940 time period; after the start of World War II, private funding that resulted in significant technology never produced more than 12 percent of the advances.

The time lag between discovery and application to a military aircraft averaged just over 3 years. In civil aviation, the time lag was longer and averaged close to 6 years.

OBSERVATIONS

The Study Group noted these observations as pertinent to the analysis and selection of significant technological advances:

1. U. S. aviation began to grow and prosper during the late 1920s. Civil aviation stimulated many early advances, but nearly all of them were influenced by Government programs.
2. Military sponsorship and first use have

characterized most of the significant technological advances since the start of World War II.

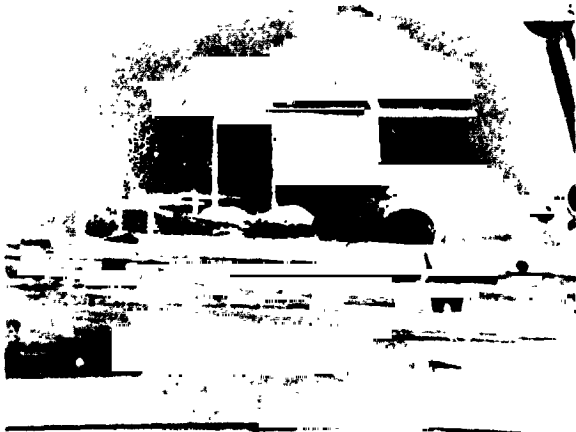
3. Military research, development, test and evaluation have usually provided the bases for later acceptance and use of technological advances in civil aviation. The outstanding example of this is the development of the commercial jet transports, which drew heavily on military experience.

4. Many contributions made aviation progress possible. In several cases, these advances originated in foreign countries; in others, they came from scientific disciplines not usually associated with aviation, such as meteorology, human factors, and medicine. In still others, they

came from Government agencies not linked to defense problems.

5. Significant new factors are beginning to influence the progress of aviation and its technology. Among these are the rapidly rising costs of research and development, public concern for the environment and other social problems, increasingly strong foreign competition in civil aviation, and a changing and evolving military threat.

6. The concept of systems analysis, pioneered by the military in the development of weapons, set a trend which is widespread now not only in civil aviation, but in a non-aviation application. Recent systems analyses of some urban problems represent a case in point.



A common major airport scene.
(Courtesy of The Federal Aviation Administration)

THE RELEVANCE OF MILITARY RESEARCH AND DEVELOPMENT PROGRAMS TO THE NEEDS OF CIVIL AVIATION

The recently completed *Civil Aviation Research and Development (CARD) Policy Study*, conducted jointly by the Department of Transportation and the National Aeronautics and Space Administration, identified three major problems that face civil aviation today: Aircraft noise, air-traffic congestion, and the lack of economical low-density, short-haul transportation systems.

The CARD Study further cited four important problem areas bearing on the future of civil aviation: Long-haul transportation, air pollution, air cargo, and maintaining the broad technological base supporting all the needs of civil aviation development.

Many current and planned military aeronautical research and development programs will contribute to the solution of the civil aviation problems defined by the CARD Study, just as past advances developed under military sponsorship have contributed to the growth of civil aviation. For even though military programs are, by their nature, directed exclusively toward solutions of specific problems in military aviation, their scope is broad enough and their results universal enough that often they may

be applied to civil aviation as well.

This section, which assesses the relevance of military aeronautical research and development, is divided into two major sections. The first examines some of the current and planned military research and technology programs that will contribute to civil aviation's growth in the future. The second considers four case histories of current commercial jet transports to show the contributions of past military development programs.

NOISE ABATEMENT

Aircraft noise abatement was assigned the highest priority by the CARD Study because of public concern for the environment and because the degree of success of the noise-abatement program will affect the solution of other problems.

Since the introduction of jet engines, military programs have been aimed at making a safe working environment for ground and flight crews, reducing the possibilities of sonic fatigue in structures and of detection during combat operations, and improving the general environment around an air base. Current programs by all three military services include the development of techniques and engines for quiet propulsion, a new technology that will have immediate application in civil aircraft.

CONGESTION

Air-traffic congestion involves the airways, air-traffic control, airport terminals, and all the ramifications of a system which includes those three elements. Air-traffic control, at the heart of the congestion problem, is one area where current and planned military programs will have a substantial influence. As one example, each of the military services has air-traffic control programs geared to the specific requirements of the unique tactical situations in which it operates. The Army is working with helicopter operations, the Navy, with carrier landings, and the Air Force, with air-traffic-control towers and centers. The knowledge gained from

these programs can be translated directly into problem solving for civil air transportation.

LOW-DENSITY, SHORT-HAUL AIR TRANSPORTATION

The lack of suitable and economical aircraft has been a major roadblock in solving the problems of short-haul transportation, both low- and high-density. But current military V STOL and STOL aircraft programs will benefit civil aviation through the transfer of technology and hardware. Military-funded programs for powerplant development for future members of these two unusual classes of aircraft will make contributions to short-haul civil air transportation.

One unusual example is an all-terrain landing gear, being developed in prototype form in a joint program by the U. S. Air Force and the Canadian Government. Such a landing gear, which works on the principle of an air cushion, would free aircraft from concrete runways or hard surfaces and enable them to land on mud flats, lakes, rivers, tundra and marsh, as well as on prepared strips.

LONG-HAUL TRANSPORTATION

For the first time in many years, there is no military long-haul transport in development or

even in planning. But there are related development programs that will benefit future civil transport designs for long-distance routes; among them are:

- *Supercritical wing aerodynamics*, now being tested in a joint DoD-NASA flight research program.
- *Three advanced engine developments* for transonic and supersonic flight regimes.
- *Automatic flight control technology* program for large aircraft.
- *Advanced materials* for major improvements in structural strength and weight.



The air cushion landing system concept.
(Courtesy of The Air Force Flight
Dynamics Laboratory)



The DC-9 transport before and after being equipped
with smoke reduction combustion chambers.
(Courtesy of Pratt and Whitney Aircraft)

The continuing availability of specialized military ground and flight-test facilities will contribute further to future transport designs.

AIR POLLUTION

The military interest in nonpolluting engines grew out of the need to reduce the chance of visual detection of combat aircraft. It was military interest in smokeless jet-engine combustion, for example, that led to the development of the special combustors now being installed in airline fleets to reduce visible pollutants.

Continuing military research programs in combustion and visible and nonvisible pollutants will help civil-aircraft designers and operators solve this pressing problem.

AIR CARGO

Military and civil cargos and cargo-handling methods differ greatly, but some military experience is transferable. New military programs for the heavy-lift helicopter and the advanced medium STOL transport will add to the data bank of cargo-handling techniques.

TECHNOLOGY BASE

The technology base is supported by broad military programs in propulsion, flight mechanics, structures and materials, avionics, flight control, vehicle dynamics, equipment, meteorology, human factors, and aviation medicine.

These generalized programs are the sources for most of the technological advances that eventually benefit civil aviation.

In flight mechanics, for example, there are programs to match jet engines with air inlets, a very critical problem area in both military and civil aircraft design. Predicting the aerodynamic characteristics of an aircraft leads to computerized design techniques, now used extensively in aircraft planning and preliminary design. Programs studying aerodynamic buffet, high-lift and maneuvering devices, advanced airfoil and wing design, and minimum drag will contribute to civil aviation progress. So

will military work on lighter structures, on new flight control techniques such as fly-by-wire, on sonic fatigue, and on environmental control systems.

ASSESSMENT OF RELEVANCE

The relevance of these military programs to civil aviation is sometimes very obvious and at other times less visible. In the following assessments made by the Study Group, the military technology is related to the needs of civil aviation in terms of high, moderate, or low relevance. Then the long-term trend of relevance is estimated, to indicate whether or not future benefits to civil aviation will continue at the same rate as in the past.

- *Noise abatement:* Relevance is low, because military projects have only recently begun to consider the same problems encountered by civil aircraft operators. An upward trend is expected.
- *Congestion:* Relevance is high between military technology and civil needs in airways congestion, but low with respect to airports. No change in trend is expected for either.
- *Short-haul transportation:* Relevance is high, with major benefits expected from military programs in development of the helicopter and STOL and VTOL aircraft.
- *Long-haul transportation:* Relevance is considered moderate, with a downward trend. Not all of the military programs have a broad base in this problem area, and there is no current program for long-range military transport aircraft.
- *Air pollution:* Relevance is moderate, because of past military work based principally on the reduction of visible pollutants, but the trend is upward.
- *Air cargo:* Relevance is moderate. Even though there are few new military projects being considered, the significance of past work warrants the current assessment of moderate.
- *Technology base:* Relevance is high, because of the many applicable military de-

velopments in all of the disciplines.

These assessments bear out the belief that future civil aircraft development will benefit from current and planned military research and technology programs. But perhaps the strongest argument for that reasoning can be shown in the case histories of commercial airliner development. There, the research and technology, the designs and equipment which came from past military programs, have coalesced in hardware.

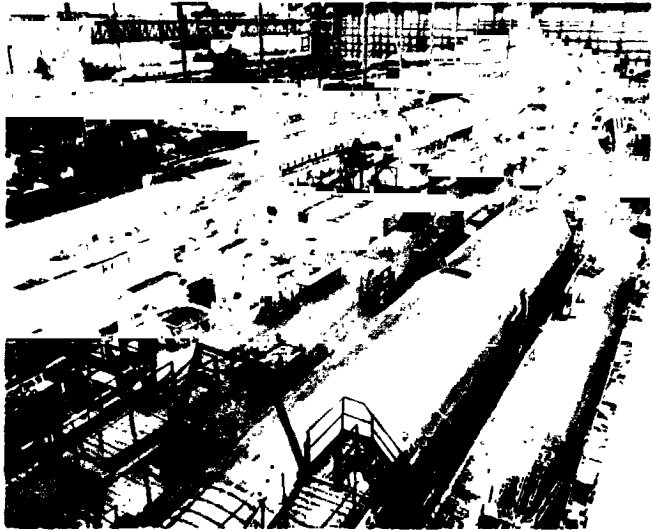
COMMERCIAL AIRLINER DEVELOPMENT

It is a multibillion-dollar effort to develop and begin production of a large commercial jet transport today. The manpower requirements are as high as four times the numbers required for developing the first generation of commercial jets. Larger and more complex facilities are needed for manufacturing, testing and checkout.

Historically, significant amounts of the capital and development costs of such ventures have been reduced through the transfer of military aircraft technology and hardware. But this transfer is a function of two important factors:

- *The difference between the design philosophies for military and civil aircraft.* Military aircraft are designed to specific mission requirements, and some degree of risk is acceptable in applying new technology for the first time. Civil transport aircraft are designed with priority on safety, economy, long service life, and passenger comfort.
- *The ratio of military to commercial business in which an aerospace company is involved.* For example, 20 years ago the facilities that produced commercial transports were Government owned. Today, a plant such as the one which produces the Boeing 747 is entirely company owned.

During the 1940s, there was direct hardware transfer between military transports and civil airliners. In some cases, only the interior arrangements and equipment differed. Civil air-



Large and complex facilities are required for the development of commercial transports.

(Courtesy of The Lockheed-California Co)

craft development also benefited from military plant and test facilities, manufacturing and production methods, tooling, and design-team expertise. This total transfer continued up to the introduction of commercial jet transports.

About then, the transfer process changed in kind but not in degree. It was technology, rather than hardware, that was transferred directly. The early military development of jet aircraft tested and proved the technological advances in design, propulsion, structures, avionics, and the other major items in aircraft development. The first generation of military jets provided the technological base on which the first generation of commercial jet transports could be built.

To assess this transfer more accurately, the Study Group considered four case histories of current U.S. commercial jet transports.

BOEING 707

Relevance: The Boeing 707 clearly traces its lineage directly from the USAF B-47 and B-52 bombers; Boeing's experience in those military programs was invaluable to the 707 development. The transfer of military technology and hardware was very high.



The Boeing 707 was the first U.S. commercial jet transport. (Courtesy of The Boeing Company)

The Boeing 707, the first U.S. commercial jet transport, was designed for high subsonic cruise speeds. It was developed as a tanker-transport prototype, the Boeing 367-80, and first flew in July 1954. It evolved from Boeing experience with the Air Force B-47 and B-52 bomber programs. The B-47, which first flew in 1947, was the most important forerunner of the 367-80, the Air Force KC-135 jet tanker, and the commercial 707. The first of the 707 series, the Boeing 707-120, entered airline service in 1958.

Specifically, the Boeing 707 owed these features to direct transfer of research, development, technology or hardware that had been originally sponsored in military aircraft programs:

- Aerodynamic and structural design data
- Flight experience with large, highly aeroelastic wings
- Lateral control by spoilers and inboard ailerons
- Nacelle placement and pylon design
- Structural design experience
- Power plant
- Autopilot and inertial navigation systems
- Approximately half the navigation systems

DOUGLAS DC-8

Relevance: The major contributions of the military to the Douglas DC-8 transport were in the technology base, design data, two complete power plants, some equipment and components, facilities, and experience. The transfer of military technology and hardware was moderate, except for the power plants, where the transfer was high.

In 1955, the Douglas Aircraft Company assembled a design team to enter the Air Force jet-tanker competition. That experience, plus the background Douglas had acquired in the development and production of a number of high-speed military aircraft, enabled the company to move into the design and production of a commercial jet transport. No prototype of the DC-8 was built; Douglas went directly into production for reasons of time and competition with the Boeing 707.



The Douglas DC-8 was developed without a prototype. (Courtesy of The McDonnell Douglas Corp)

These features of the DC-8 program were traceable to earlier military programs in research, development, technology or hardware:

- Air Force manufacturing facilities
- Aerodynamic and structural design data
- Numerically controlled tooling
- Approximately 40 percent of flight control technology

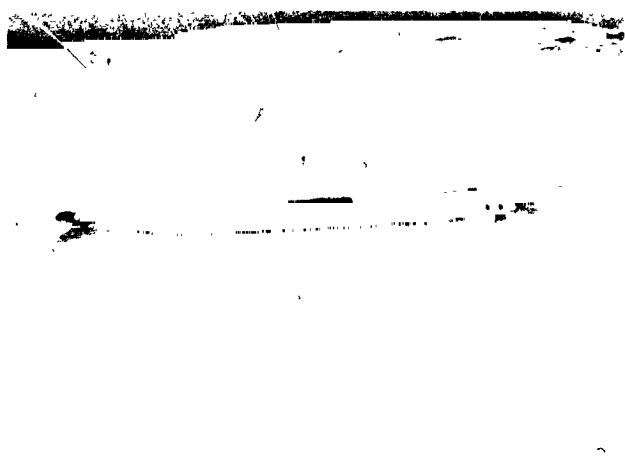
- Power plants for early and later models of the DC-8
- Approximately 40 percent of the avionics equipment

BOEING 747

Relevance: Much of the basic technology and development base of the Boeing 747 is traceable to military programs. The propulsion system of the airplane was the key to its success, and it drew on the development of the high-bypass-ratio turbofan engine, sponsored by the Air Force, for many of its technological advances. Overall, the direct transfer of military technology and hardware was low to moderate, the only exception being the high transfer in basic power-plant design.

The design team that had developed Boeing's proposals for the Air Force C-5A program was the backbone of continuing company efforts with large transport design. With Boeing's previous experience in commercial jet transports as additional data, the company was ready to try the problems of developing a very large transport for long-haul routes. The first delivery of a production 747 aircraft was made in December 1969.

The 747 features that drew from the back-



The Boeing 747. (Courtesy of The Boeing Company)

ground of military research, development, technology and hardware included:

- Design information from extensive wind-tunnel testing and analyses during proposal work for the military C-5A program
- Structural design technology
- Configuration and aerodynamic design data
- Air Force flight-test facilities
- Titanium forgings from the heavy press program
- Approximately half of the flight-control technology
- Power-plant technological advances
- Most avionic system components



The McDonnell Douglas DC-10.
(Courtesy of The McDonnell Douglas Corp)

MCDONNELL-DOUGLAS DC-10

Relevance: The McDonnell-Douglas DC-10 did not benefit as much from military program knowledge and experience as the earlier jet transports in these histories. In general, transfer of technology from the military was low to moderate, except for the power plant, where the transfer was considered to be high and was significant in saving costs and reducing program times.

This large-bodied transport was developed, like the earlier DC-8, around conservative design goals and criteria in order to minimize the

risks and shorten the development time. Like the 747, it was designed to take full advantage of the characteristics of the high-bypass-ratio turbofan engine. This aircraft entered service in 1971.

There were major contributions to the DC-10 program as a result of earlier or parallel military programs, and they included:

- Aerodynamic design and data contributions to an improved airfoil section, to nacelle and pylon drag increments, and to the double-slotted wing flaps
- Structural analysis techniques in fracture toughness and fatigue;
- Origins and development of redundancy concepts in the flight control system
- About one-half of the autopilot technology
- Extensive power-plant technology, plus military flight experience with the engine
- Less than 30 percent of communications and navigation equipment, but some degree of transfer in electronic systems techniques.

TRENDS AND OBSERVATIONS

In the past, the technology and hardware that were developed for military swept-wing jet aircraft provided a firm foundation for the development and production of the first commercial jet transports. These transports that first flew in the 1950s could trace their lineage to military programs of the previous decade. But beginning in the mid-1950s, there was a reduction in the number of large military aircraft development programs, and one of its first effects was to reduce the transfer of hardware to civil aircraft.

The current generation of wide-bodied commercial jet transports required no new design technology other than that of the high-bypass-ratio turbofan engines. But the detailed design of these big airliners did take advantage of technology derived from military programs.

The next generations of commercial transports, including those considered for STOL operations, will benefit from new military aircraft prototypes and advances from research

and development. But the trend in the transfer of hardware and development experience from military programs to large, long-haul commercial aircraft has been downward, and the future trend is uncertain at this time.

Overall the trend in direct transfer of hardware—as opposed to the transfer of research and technology—has been downward. Until the mid-1950s, there was a direct transfer of hardware, such as complete power plants, identical fuselage structures, tail surfaces, and landing gear. More recently, the trend has been limited to the direct transfer of smaller systems and components, such as hydraulic systems or inertial navigation systems.

The overall assessment of the trends in hardware, or the development base, is shown in Figure 1. The upward trend in future years reflects the relevance of the military advanced medium STOL transport program, and the leveling—or slightly downward—trend probable in the long-haul transport area. What actually will occur depends on the success and progress of military research and development programs now in being, or planned, and on the new commercial transport programs that might be started.

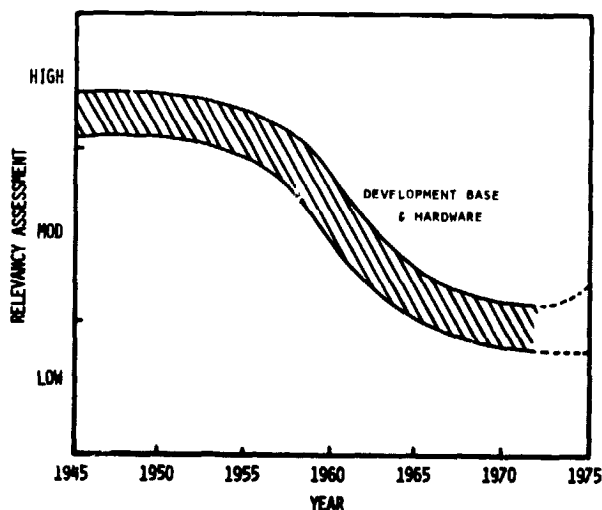
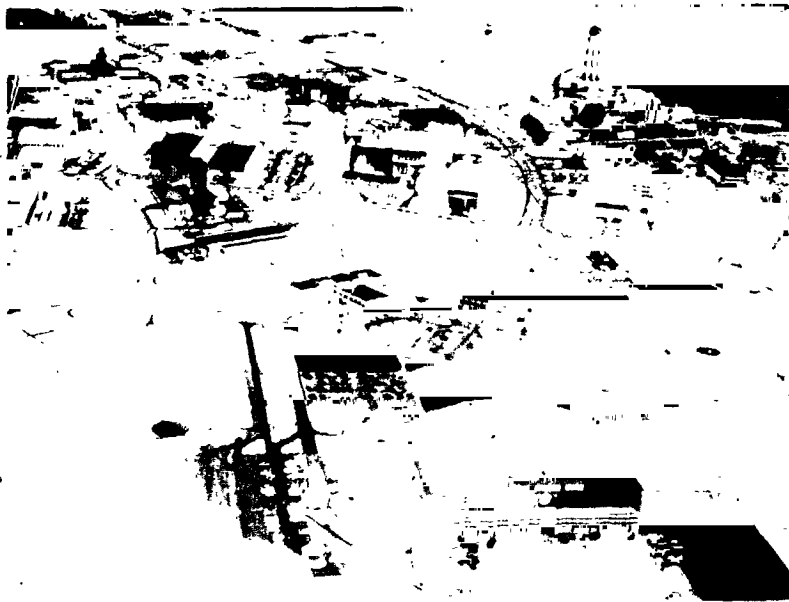


Figure 1. Military Development Contributions to Commercial Airliners



The NASA Langley Research Center has provided extensive and invaluable ground and flight test data to aid the progress of aviation.
(Courtesy of The NASA Langley Research Center)

NATIONAL SUPPORT OF AERONAUTICAL RESEARCH AND DEVELOPMENT AS MEASURED BY R&D FUNDING

One measure of the national effort that supports aeronautical research and development—and therefore the growth and progress of aviation—is the money appropriated for that research and development by both private and public sectors of the country.

This section presents some of the trends in aeronautical research and development funding in the graphs and discussions which follow. First, a few definitions:

- *Research and technology funds* are spent on basic and applied research.
- *Development funds* are spent on the development of prototype aircraft, their test programs, construction of research and development facilities, salaries for military and civilian personnel, and other support costs.
- *R&D* means research and development and includes both items listed directly above.

- *Federal defense funds* include those of the Army, the Navy, the Air Force, and the Advanced Research Projects Agency; the Aircraft Nuclear Propulsion Program of the Atomic Energy Commission; and the R&D funds reimbursed by the Government to industry as allowable costs on procurement contracts.
- *Federal non-defense funds* include those of the National Aeronautics and Space Administration and the Federal Aviation Administration.
- *Industry funds* include nonreimbursable industrial independent research and development and specific development funds, as well as those from universities and foundations.

Historically, the long-term pattern of total U.S. expenditures for aeronautical research and development has shown an upward trend. So have the individual elements of that total national support: Federal defense funds, Federal non-defense funds, and industry funds. This general increase in dollars available for aeronautical R&D is expected to continue.

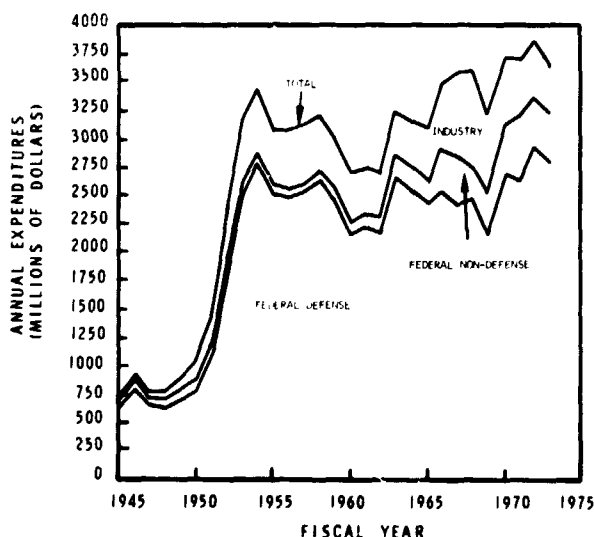


Figure 2. Sources of Aeronautical R&D Funds (1973 dollars)

The data of Figure 2 have been adjusted for inflation and are presented in terms of the value of the dollar for FY 1973. Three trends show clearly:

- The Department of Defense will continue to make substantial contributions to aeronautical research and development in the future.
- Federal non-defense agencies also will contribute to aeronautical R&D in substantial amounts.
- Industry will contribute less in the future than it has in the past. Since 1968, the industry element of funding has declined, in terms of FY 1973 dollars.

Two elements of Government research and development funding—research and technology funds and development funds—have been plotted in Figure 3, with values adjusted to FY 1973 dollars. The figure highlights the large share that Federal defense agencies contribute to both elements, and leads to the logical conclusion that continuing advances in technology can be expected from the military programs.

Research and technology funds show a slightly increasing trend over the years. About two-thirds of total research and technology money now comes from Federal defense funds, and more than 10 percent from Federal non-

defense funds. These two sources have shown an increasing support of research and technology and development over the years. Not shown in Figure 3 is the fact that industry's share of total R&D funding has decreased significantly. Consequently, the overall pattern is one of proportionately more significant future contributions as a result of Federal agencies' support.

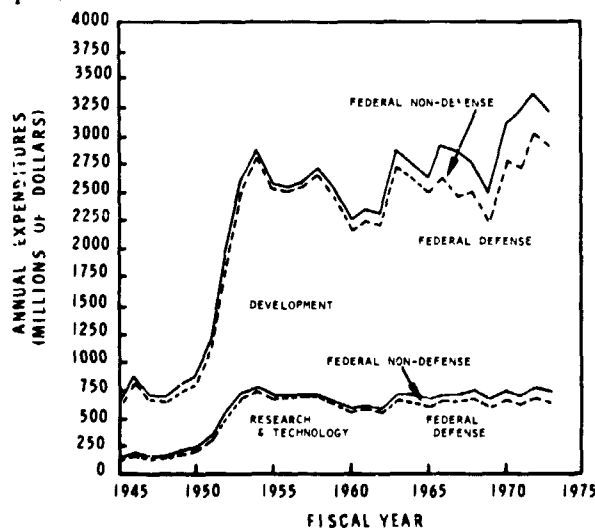


Figure 3. Government Aeronautical R&D Funding (1973 dollars)

Although a slight upward trend in Government research and development still persists, inflation has had a leveling effect. In addition, Government funding for research has been decreasing. The total purchasing power of dollars available for research and technology, however, has remained almost unchanged, because the money available for development has slightly increased.

Presenting the aeronautical research and development funding as a percentage of the gross national product (Figure 4) points up one very significant fact:

Although the gross national product has increased each year, with two exceptions, since 1945, aeronautical R&D funds have experienced a severe reversal in their earlier upward trends. Since 1954, aeronautical R&D funds have been a sharply declining portion of the GNP.

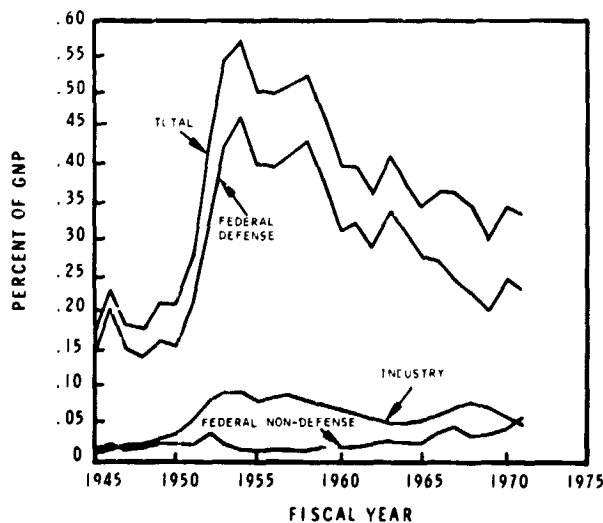


Figure 4. Sources of Aeronautical R&D Funds (Percent of GNP)

AIRCRAFT DEVELOPMENT AND UNIT COSTS

Because of the increase in complexity arising from the demands for ever-improved systems performance, the cost of developing aircraft has risen dramatically over the years. Historical trends indicate a doubling every 5 years in the cost of transports. And because these development costs have risen, the unit price of aircraft has also gone up since R&D costs must be prorated over the production run.

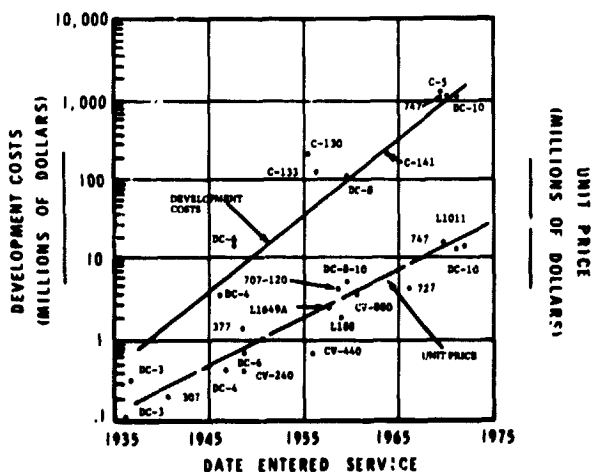


Figure 5. Transport Aircraft Development Cost and Unit Price

LONG-TERM COMPARATIVE TRENDS

Some of the most important cost and funding trends that apply to aeronautical research and development are combined in the graph that follows.

That picture is not a promising one. The significance of the long-term trends is that unit prices and development costs of civil transport aircraft are rising faster than the GNP. And funds for aeronautical research and development are rising slower than the GNP. There can only be two results of these disturbing trends: Major new aircraft programs either will decrease in number or will change in nature.

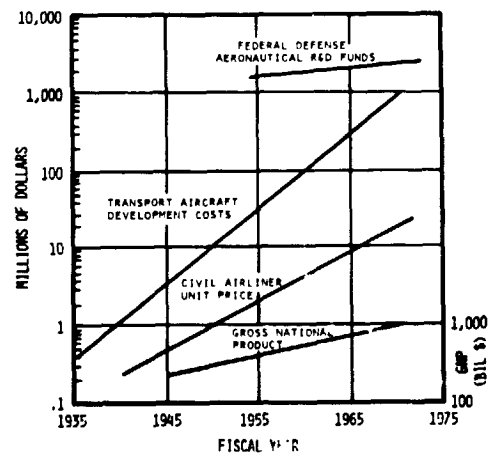


Figure 6. Summary Comparative Trends

The importance of these trends cannot be overstated. New technology results in better products that meet the customers' needs. Customer purchases result in improvements in the economy and in this country's balance of trade and balance of payments.

AIRCRAFT DEVELOPMENT STARTS

During the 1940s and 1950s, prototype development was the standard procedure for developing and testing military aircraft before production orders were placed. But the use of this approach began to decline in the 1950s, and by the 1960s had almost been abandoned.

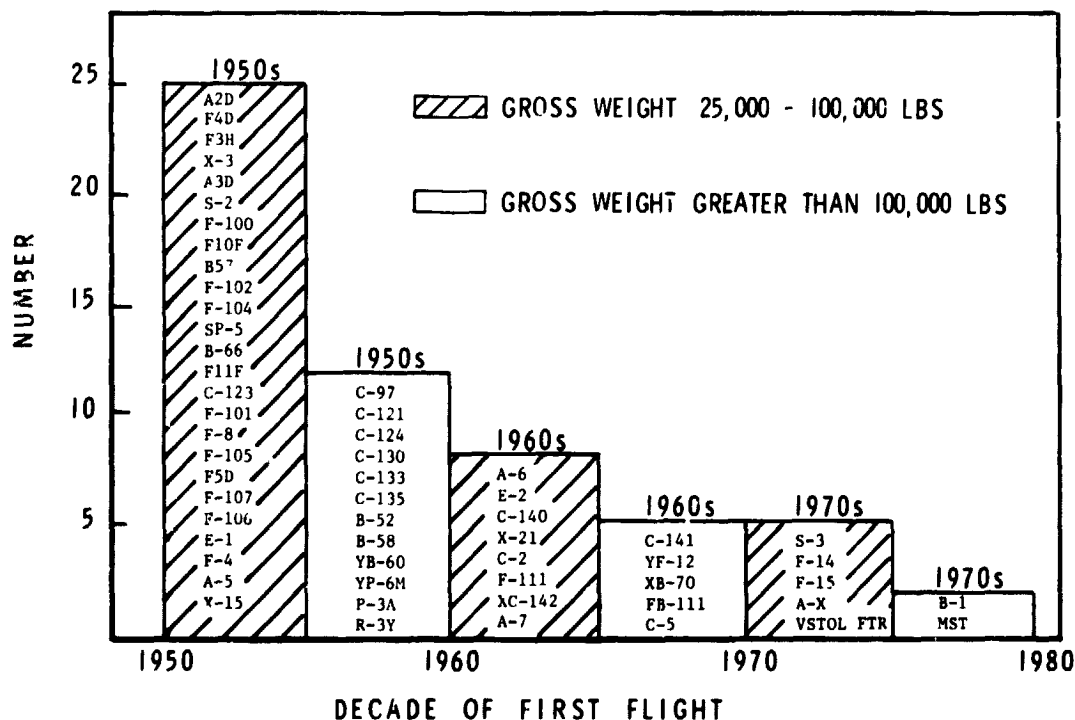


Figure 7. Military Aircraft Programs

Recently the concept of advance prototyping has been revived in the "fly-before-buy" concept. It is perhaps too early to assess the future impact of this revived approach on new program starts, but one fact stands out:

- The number of new military aircraft program starts has been sharply declining over recent years (Figure 7).

The importance of this fact lies in understanding that any successful industry grows on its momentum. Within the aircraft industry, that momentum is generated by the continuing development of new aircraft or prototypes, so that scientists, engineers, technicians and draftsmen maintain their proficiency, their expertise, their familiarity with the manifold

problems of aeronautical development. It is difficult to design one new airplane every 10 or 15 years—which is now the fact in a majority of this country's aircraft companies—and maintain the necessary proficiency and, therefore, the momentum that in the past has carried the U.S. aviation industry to world-recognized technological superiority.

Consequently, it follows that, in order to maintain the momentum that produces growth, there must be a continuing number of new aircraft-program starts to challenge the inventiveness and ingenuity of the industry. A program designed to meet established military needs, if adequately supported by Congress, should provide this necessary industry stimulus.

FINDINGS AND OBSERVATIONS

The findings of the Study Group are summarized below. Following them, the Group has recorded some observations of significant factors that now are influencing the relevance of military aeronautical research and development programs to civil aviation, and also are influencing aviation progress and the technological advances that will occur in the future.

FINDINGS

- Government sponsorship, primarily military, has provided the impetus for most of the significant technological advances that have been made by the U.S. aviation industry, by Government and private research organizations, and by universities and colleges.
- The military establishment has provided the funding for about 70 percent of the most significant technological advances in U.S. aviation between 1925 and 1972. Government civilian agencies have funded about 20 percent, and private industry has funded about 10 percent of these advances.
- The military has been the first to use about 75 percent of those gains in technology, building a foundation of operational experience that led to the acceptance and use of that technology in civil aircraft programs several years later.
- Military ground-based and flight research facilities have made invaluable contributions in the development of civil aviation. Manufacturing technology, production methods, tooling, and facilities derived from military programs have had a major positive influence on the development of civil aviation.
- Aeronautical research and technology generated by current military programs will continue to benefit civil aviation progress. In contrast, the benefits to civil aviation from military development and production programs generally have decreased in both relevance and importance. But in short-

haul air transportation, the downward trend in the transfer of hardware should reverse, and the relevance of military programs in this area should increase in the future. For long-haul air transportation, there will be little future change in the current low-to-moderate relevance of military programs.

OBSERVATIONS

- Aviation has developed to the point where it is now accepted as basic to the American way of life. It no longer enjoys the enthusiastic public support that marked its spectacular progress in the past. Now it must face the challenges of society as just another industry or service.
- The problem of congestion caused by increasing air traffic has affected civil airline operations significantly. This adds a new dimension to the overall problem of air traffic control, and has resulted in a joint approach by military and civil aviation to the solution of that problem.
- The drive for higher performance and increased productivity for modern aircraft has led to increases in the complexity of aircraft and, in turn, to increases in cost and acquisition time. As a result, and because the availability of development funding has not risen at the same rate, there now are fewer new aircraft programs. This trend will continue, unless performance demands on new aircraft are substantially changed or unless development funding is substantially increased. However, such an increase in development funding must not be at the expense of research funding. Progress in technology requires a long-term approach, both research and development being funded with equal consideration of their individual and interrelated importance.
- The amount of aeronautical research and development funding is substantial and has been rising steadily over the years. This is still true if inflation is taken into

account, although the rise is not then as rapid.

- When compared to the gross national product, to total expenditures for Government research and development, or to the rate of increase in aircraft development production costs, the trends of aeronautical research and development funding are unfavorable. Aeronautical research and development funding, as a percentage of GNP, or of the total Government funding for research and development, is on the downward trend.
- Current military interests in short-haul air transport developments, both V-STOL, and STOL, should yield many benefits to

civil aviation, especially if the projected programs continue.

- The current absence of a firm military requirement for a new long-haul transport could have a significant impact on the technology and development base that historically has existed for civil airliner development.
- Any decrease in the current relevance of military aeronautical hardware to the needs of civil aviation could add even further to the already increasing costs of civil airliner development. These costs have risen dramatically and will be major considerations in any new airliner development and production program.